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Rehabilitation Design And Systems Analysis Of The Cable Car Facilities

Report on Sector II
(Trackway Systems Analysis)
to the San Francisco
Municipal Railway (MUNI)
Transit Improvement Program

Volume I:
Introduction and Summary

24

Chin & Hensolt Engineers, Inc.
June 1979

Rehabilitation Design And Systems Analysis Of The Cable Car Facilities

**Report on Sector II
(Trackway Systems Analysis)
to the San Francisco
Municipal Railway (MUNI)
Transit Improvement Program**

**Volume I:
Introduction and Summary**

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June 8, 1979

Mr. Rino Bei
Program Manager
Transit Improvement Program
San Francisco Municipal Railways
949 Presidio Avenue, Room 150
San Francisco, California 94115

Dear Mr. Bei:

We are pleased to submit herewith the report on our systems analysis of the San Francisco cable car trackway and certain related equipment. It includes results of our on-site inspection and evaluation of every trackway component, the cable, and energy requirements. It also includes our recommendations for the rehabilitation of the trackway.

Because we know it will be some time before a rehabilitation program can begin, we have made recommendations for interim repairs that are necessary to keep the cable car system in service.

We appreciate very much the opportunity we have had to work on a project of such importance to San Francisco.

Very truly yours,

CHIN & HENSOLT ENGINEERS, INC.

P. Q. Chin
President

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SYNOPSIS

As a result of our inspection and evaluation of the trackway, Chin & Hensolt has concluded that an extensive rehabilitation is necessary if safety and economy are to be restored to the cable car system. Conduit yokes are so corroded that their continued ability to sustain cable car and vehicular traffic loads is doubtful. Brick construction of the California-Drumm, Powell-Market, Powell-Washington, and Bay-Taylor sheave pits and Powell-Market turntable pit is badly deteriorated and inadequately reinforced, and beams in the other sheave pits are rusted. Many carrying and pull curve pulleys are malfunctioning or missing from their stations. Depression beams are not designed to bear safely the impact of heavy traffic. About two thirds of the running rail, one third of the slot rail, and half the switch, mate, and frog rails are badly worn. Many pull curve chafing bars are worn and loose. The turntables are in disrepair. Hatch covers are corroded, warped, and worn, and covers at pull curves are too heavy for one man to lift, which discourages proper maintenance.

This deterioration of the trackway is caused not only by age, but also by neglect. Malfunctioning and missing pulleys and loose chafing bars are due primarily to inadequate maintenance, while other substandard conditions result primarily from a lack of capital investment compounded by poor maintenance.

To rehabilitate the trackway Chin & Hensolt recommends:

- o Replacement of conduits, incorporating pre-fabricated concrete sections;
- o Reconstruction of California-Drumm, Powell-Market, Powell-Washington, and Bay-Taylor sheave pits and Powell-Market and Bay-Taylor turntable pits, and reconstruction of the roofs of the other sheave pits;
- o Establishment of a uniform pattern for pulleys, based on results of a testing and evaluation program for improvement of design and materials;
- o Investigation of a means of eliminating depression beams;
- o Use of girder running rail or, if girder not available, 60 lb Tee rail throughout the system (and, under the rehabilitation program for the cable cars, replacement of present car wheels with ones having flanges at least 5/8 in. in depth, instead of the present 11/32 in.);
- o Use of uniform slot rail, with beveled ends to prevent dislocation that might catch grip;
- o Repavement with asphalt near rails, except for brick at Powell St mall and Market-Drumm terminus;
- o Establishment of minimum 50 ft radius for all pull curves where possible, and replacement of present chafing bar with Tee rail;

- Replacement of most bumper bars with limit switches to shut down winding machinery automatically if gripman passes let-go warning point without dropping cable;
- Replacement of present turntable with electrically operated ones;
- Redesign of hatch frames and covers, with a view to restricting weight to be lifted by one man to 50 lb;
- Installation of railroad-type flashing red lights at various pull curves and intersections, more strand alarms to provide one every 2000 ft, an automatic lubrication system for sheaves and other equipment, a communication system between cable car and barn, and a mini-computer to monitor trackway conditions and car operations.

A testing and evaluation program should be established to investigate different lubricants to replace the pine tar used for the cable, high molecular weight polymer for pulley facings and other equipment, and steel alloys for the grip dies and cable car wheel rims.

To assure efficient maintenance, authority for providing maintenance of all components and seeing that tasks are performed might be invested in a single MUNI administrative department or independent authority.

Rehabilitation of the trackway should be concurrent with rehabilitation of the barn. The work can be completed within two years if all operations are suspended, or it can be phased.

Costs of rehabilitating the trackway within a two-year period are estimated at $21,687,000 in June 1979 prices and $31,970,000 at midpoint of construction in September 1982 prices (calculated on the basis of a monthly escalation of one percent, compounded).

Because a substantial part of the increase from $21,687,000 to $31,970,000 is due to anticipated inflation, serious consideration should be given to design and construction methods that involve fast-tracking.

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Appendix. On-Site Inspection Records

Part 1

Introduction and Summary

As part of its Transit Improvement Program, the San Francisco Municipal Railway (MUNI) commissioned Chin & Hensolt Engineers, Inc. to design the rehabilitation of the cable car barn and conduct a systems analysis of the cable car trackway. This report covers the inspection and evaluation of the trackway and includes recommendations for its rehabilitation (Sector II of the Scope of Work: Agreement between City and County of San Francisco and Chin & Hensolt Engineers, Inc., dated January 3, 1978).

Section 1.1

SCOPE OF WORK

Systems analysis may be defined as the collection and evaluation of data about the components of a system in order to determine their functional and economic efficiency with respect to the design and purpose of the system. In the case of the cable car trackway, the components include approximately 50,000 ft of conduit underneath the city streets, 10 sheave pits, 97,000 ft of running rail, 99,000 ft of slot rail, 19 switches, 1900 pulleys of various types, 71 depression beams, 2300 hatches, 1400 ft of chafing bar, 14 bumper

bars, 5 take-rope gypsies, 7 safety latches, 3 turntables, 58 traffic signal control switches, and related equipment. As far as possible, every component was thoroughly inspected, available maintenance records were scrutinized, drawings and specifications were studied, and evaluations were made by staff engineers and consultants.

Section 1.2
DESCRIPTION OF THE TRACKWAY

The system comprising these components is remarkably simple. From one drive machine, whose design has changed very little since the nineteenth century, three cable car lines totaling 9.4 mi of track are operated:

(1) The California line, which runs on California St from Van Ness Av to Drumm St;

(2) The Powell-Mason line, which begins at Powell and Market sts, follows Powell St, turns west on Jackson St, runs north on Mason St to Columbus Av, then after following Columbus turns onto Taylor St and terminates at Bay St; and

(3) The Hyde line, which proceeds along the route of the Powell-Mason line but continues on Jackson St to Hyde St, where it turns north and continues to Victorian Park just north of Beach St. (See Figure 1.2.a.)

A small stretch of nonrevenue track from California St to Washington St on Hyde is used to transfer cars between the barn and California St at the beginning and end of each day's operations.

1.2.1 The Cable

About 55,250 ft of cable are used in the system. The cable -- or "rope" -- is 1-1/4 in. in diameter and is made of six strands, each containing 19 plow-steel wires, wrapped clockwise (right lang lay) around a sisal core (see Figure 1.2.b). It is impregnated with pine tar, which is also used for external lubrication. The cable is driven at a speed of 9.54 mph. To operate a cable car, the operator (gripman) closes the jaws of the grip around the cable. When the cable is finally engaged, the car is propelled at 9.54 mph, but slower speeds can be obtained for short distances by gripping the rope loosely. (See Figure 1.2.c.)

1.2.2 The Conduit

Each line has its own cable, except that the Hyde line uses the Powell-Mason cable on Powell St. All three cables are driven simultaneously by the winding machinery and pass through conduits approximately 53 in. wide and 36 in. deep, with channels 10 in. wide and 26 in. deep, which run just below the surface of the streets. On the California and Hyde lines, the walls are made of concrete. On the Powell-

Mason line they are unreinforced brick with a concrete foundation. Iron frames called yokes are imbedded wholly or in part in the walls at intervals of from 36 to 52 in. Rail and other equipment are supported by the yokes. (See Figure 1.2.d.)

1.2.3 Sheave Pits

Since each cable is continuous, it must be guided from the barn to its appropriate conduit and turned around at the terminal of the lines by large sheaves placed in vaults beneath the street. The largest vault extends catercorner from the barn under the intersection of Washington and Mason sts. Ten others, referred to as the sheave pits, are located throughout the system, with access by vertical hatches opening into the street. The pits vary in size, but are about 16 by 16 ft and 7 ft deep. Most were built in 1956 or 1957, after the acquisition by MUNI of the California line, and their construction is of concrete, with steel beams. The rest are all-brick or brick and concrete with corbeled arch roofs supported by steel beams. Sheaves in the pits are 10 or 12 ft in diameter and are made of steel, iron, or steel and iron combined. All have brass bearings and are mounted on cast iron "U" frames or pedestals.

1.2.4 Pulleys

As it travels through the conduit the cable is supported by

idler pulleys ranging in diameter from 9-1/8 to 42 in. Of the approximately 1900 in the system about half are "carrying" pulleys 9-1/8 to 9-1/2 in. in diameter, placed at 30 to 40 ft intervals on metal or wood supports resting on the bottom of the channel or (in some instances on the California line) anchored to the walls. The cable is deflected at the crests of steep hills by "crown" pulleys 20 to 42 in. in diameter, and is guided around curves by horizontal pulleys, most of them 24 in. in diameter. About two thirds of the pulleys in the system are cast steel, one fifth are cast iron, and the rest are cast aluminum with polyurethane facing bonded to the perimeter. More than half the pulleys have babbitted bearings packed with grease, about 16 percent brass bearings packed with grease, and the rest antifriction bearings lubricated by grease placed directly on the bearing or fed through a hole in the shaft.

1.2.5 Depression Beams

To prevent the cable from rising to the top of the channel at the foot of steep hills, it is held down by a pair of 5 in. pulleys mounted on a movable arm, which is pushed aside by the grip when it passes. The two main types of depression beam, as the device is called, are distinguished primarily by the mechanisms that return the arm to its position over the cable after the grip has passed. Attached by a pivot to a fixed frame, the arm of the Powell type is

swung horizontally along guide bars and returned by a counterweight (see Figure 1.2.e). The arm of the Hyde type rests on a pivoting vertical bar and is returned in a vertical arc by a spring coil (Figure 1.2.f). Two experimental types are being tested in the trackway. The first is identical to the Powell, except that the arm is made of steel, whereas the Powell's is composed of wood and brass contained by a steel frame. The second is similar to the Hyde type, differing principally in fabrication and its use of a leaf spring to return the arm.

1.2.6 Rail

The cable car rides on 3-ft 6 in. gauge track mounted on "chairs" attached to the yokes. In the center of the track are two rails about 3/4 in. apart with a slot between them directly over the cable. The shank of the grip runs through the slot, its jaws travelling about 13 in. beneath the surface. At least 11 types of running rail, joined in patchwork fashion, are used in the system, including remnants from horsecar days. Most is 50 lb Tee rail or 55 lb Trilby (girder). Three kinds of slot rail are used: 40 lb slot, 7 in. "Z"-bar slot, and 5 x 3-1/2 x 1/2 in. angle, the last an improvisation due to the fact that slot rail is no longer manufactured. The cable car right of way extends 24 in. beyond the outside of the track. (See Figure 1.2.g.)

1.2.7 Pavement

Several kinds of pavement are found, sometimes interspersed, in the right of way. Asphalt is the most common, followed by concrete. Brick has been newly laid in the mall on Powell St between Eddy and Market sts and at the Market and Drumm terminus, and an old stretch still exists on Powell south of Geary St. Patches of ancient cobblestone crop out of thin overlays of asphalt on Hyde and elsewhere. Pavement plate ordinarily is 1/4 in. steel, but where the metal has corroded through or otherwise been destroyed rags and other makeshift filler have been used. Pavement in the right of way is maintained by the Department of Public Works at MUNI's direction.

1.2.8 Pull Curves

In turning 12 of the system's curves, the cable car is pulled by the cable (thus the term "pull curve") at 9.54 mph. Since the car follows a circular path and the cable, guided by horizontal pulleys, tends to follow the path of a polygon, there is considerable lateral force on the grip. To prevent the grip from bending, a curved, flat, 3-in.-high steel "chafing" bar maintains the jaws of the grip in an upright position. The bar is set with great precision just above and in front of the pulleys and is anchored to yokes spaced at short intervals to form a curve. (See Figure 1.2.h.) At other curves the grip is

disengaged from the cable and the car drifts around the curve on its own momentum -- hence the term "drift curve." (See Figure 1.2.i.)

1.2.9 Bumper Bars

When two cables cross, as at Powell and California sts or Mason and Jackson sts, the car on the lower -- "inferior" -- cable must let go of the cable and drift across the higher -- "superior" -- cable. If the gripman of the car running on the inferior line fails to let go, the cable, held high by the grip, raises a heavy steel "bumper" bar mounted across the channel, and a counterweighted lever with a pulley and bell attached is released. The pulley presses against the cable and turning, rings a warning bell. If the gripman still fails to let go, the bar rips the cable out of the jaws of the grip, frequently causing severe damage to the cable. A glass vial taped to the bar breaks and white paint is splattered on the grip so that the offending car can be unmistakably identified. Bumper bars are also on the approach to the turntables and bend sheaves and at other points where it is desirable to have the cable out of the grip.

1.2.10 Dips and Take-Rope Gypsies

Because the cable ordinarily runs about 2-1/2 in. below the grip, the gripman cannot retrieve it at will after dropping it at a let-go point. At five locations on hills the car is

allowed to coast forward until the grip meets the cable where it rises near a depression beam, and at seven other let-go points the car drifts to a 5 in. dip in the trackway, which lowers the forward truck enough for the grip to retake the rope. On the inbound track just off the turntable at Bay and Taylor sts and at four other places, the conductor lifts the cable into the grip by means of a take-rope gypsy. The device consists of a lever in the street connected to a subsurface pulley. When the lever is raised the pulley lifts the cable. (Figure 1.2.j.)

1.2.11 Safety Latches

At five locations the cars ascend steep grades where the automobile and pedestrian traffic might make it necessary for the gripman to drop the cable and apply the hand brake before the car reaches the summit. To prevent the car from rolling back more than a few feet in the time it takes the gripman to brake after letting go of the cable, a 4 x 1 in. steel bar is placed diagonally across the slot to block the grip. Like depression beams, the bar pivots to permit the car to pass in a forward direction. At the crests of Powell St at California and of Hyde St at Chestnut a second safety latch has been installed farther down the hill. (See Figure 1.2.k.)

1.2.12 Turntables

Turntables are used to redirect the single-end Powell-Mason type cars at three termini: Market and Powell sts, Bay and Taylor sts, and Victorian Park near Hyde and Beach sts. About 19 ft in diameter, they have wooden decks framed by steel and rotate on twelve 11 in. steel bearing wheels placed between circular rails. All the tables are rotated manually, and the latches that lock the tables into place are released manually by means of a lever or pull cord. The pits housing the turntables at Victorian Park and Bay and Taylor sts have concrete foundations and walls, but the pit at Powell and Market -- which was built in the late 1880s -- has brick walls.

1.2.13 Hatches

Subsurface equipment and installations are reached from the street through hatches that vary in size from 10-1/2 x 15-1/2 in. for the small carrying pulleys to 16 by 36 in. for pull curve pulleys to 10 by 69 in. for depression beams to 28 by 84 in. for the sheave pits. The frames are iron or steel and the covers are iron, steel, or wood.

1.2.14 Electrical Equipment

The only electrical equipment in the trackway are magnetic sensors that operate traffic signals; special traffic lights for cable cars (crossbucks), which are operated either by sensors or manually; and strand alarms, which automatically

shut off the drive machinery. Placed where the grip passes, a sensor located before a traffic light turns it green for the cable car, and a sensor placed after the light returns it to its regular cycle. The strand alarm is a U-shaped device (see Figure 1.2.1) that is pushed forward when it intercepts a broken strand, closing a switch and shutting off the drive machinery; the cable travels about 80 ft before it stops.

Section 1.3
HISTORY OF THE TRACKWAY

The source of many problems in the trackway can be found in the history of the present cable car system. The Ferries and Cliff House Railway, on which the system is based, was built between 1886 and 1888, and much of the conduit laid for the original Powell St and Mason St lines is still in use. In 1893 the Ferries and Cliff House Railway merged with the Market Street Cable Railway (opened in 1883) and Omnibus Railroad & Cable Company (1889), then in 1902 the 25-year-old Sutter Street Railway was added to the company, which adopted the name United Railroads of San Francisco. Although the lines were kept separate, United Railroads had at its disposal a potpourri of equipment, a resource that soon proved to be providential. Because of the extensive destruction of trackway and equipment in the earthquake and fire of 1906, the company was faced with the choice of rebuilding the devastated lines or abandoning them in favor of the more efficient electrical streetcar, whose

advent to transportation had followed shortly the introduction of the cable car. The company decided on the latter for most of the old Market Street and Sutter Street cable car lines (the Omnibus was already defunct), and in reconstructing the remainder used whatever equipment was at hand. What began as necessity and convenience became something of an economic policy after United Railroads went bankrupt in 1918 and reorganized three years later as the Market Street Railway. Rail, for example, was bought anywhere it could be found, with the result that quite different types in diverse condition were combined in the trackway. The San Francisco Municipal Railway acquired the Market Street Railway's lines, now further abbreviated, in 1944, and in 1952 bought the 74-year-old California Street Cable Railway, which included the Hyde St trackage of the present system. Some alterations and new construction were required to drive all the lines with the winding machinery at the Washington-Mason barn and to center the California St slot over the cable so that the side grip used by that line could be replaced by the Eppelsheimer bottom grip used by the rest of the system, but the California St and Hyde St trackways remained very much as they were built. Thus the present cable car system is old and consists of disparate, sometimes barely compatible equipment.

Section 1.4

MAINTENANCE OF THE TRACKWAY

To keep such an ancient and patchwork system running efficiently requires diligent, unrelenting preventive maintenance. Conduits have to be cleaned to prevent accumulation of dirt and debris that could interfere with the smooth, safe operation of subsurface equipment. Pulleys have to be lubricated regularly and worn or faulty parts must be fixed or replaced promptly. Special attention has to be given to depression beams, because malfunctions can cause -- and have caused -- serious accidents. Running rail, slot rail, and chafing bars must be kept tight and in alignment, and must be replaced when worn. A week should not pass without inspection of every trackway component and performance of assigned maintenance.

Section 1.5

INSPECTION AND EVALUATION

But the Chin and Hensolt inspection revealed that in addition to the predictable deterioration of the system due to age, maintenance has been so deferred or badly neglected that the trackway is in a state of acute disrepair. Maintenance records demonstrate that months go by without careful inspection of all the equipment, and even when a malfunction, broken part, or dangerously worn segment is obvious at a glance corrective

measures are sometimes delayed beyond reason. Age and neglect are destroying the cable car trackway.

Chin & Hensolt bases this conclusion on the following inspection results and evaluations (unless otherwise stated, inspection data are for the period March 15, 1978 through March 15, 1979 and represent for statistical reasons the single observations noted on the inspection records in Appendix A, although many components were examined more than once).

1.5.1 Cable

Purchase specifications are so loose that delivered cable sometimes does not have the properties necessary to meet the needs of the system. Friction and tension caused by pull curves and malfunctioning pulleys shorten cable life. The primary reason for the relatively long life of the California line cable, as compared to the Powell-Mason's and Hyde's (222, 48, and 56 days respectively), is the number of pull curves in the last two lines. Some of the external pine-tar lubrication accumulates in the channel, blocking drainage and causing pulley malfunctions.

1.5.2 Conduit

Yokes throughout the system are badly corroded, and it is doubtful that they can continue to sustain the loads of cable car and vehicular traffic. Walls and foundations appear to

be in good condition, but the California line slot tends to close in hot weather due to expansion of the adjacent pavement and lack of lateral reinforcement of the conduit. Drainage is generally very poor; in about one fourth of the channel the accumulation of debris is sufficient to slow or stop pulleys.

1.5.3 Sheave and Turntable Pits

Brick construction in the California and Drumm, Powell and Market, Powell and Washington, and Bay and Taylor sheave pits and Powell and Market turntable pit is badly deteriorated and inadequately reinforced. The roof of the California-Drumm pit is failing, and a section of the brickwork is fractured. An open sewer runs through the Powell-Washington pit. The Bay-Taylor pit floods at high tide during heavy rains. The concrete pits on the California line and near the Hyde and Beach terminus are in good condition, but the beams require cleaning and painting. Drainage in most pits is inadequate. Narrow hatches and steep metal ladders make access to the pits difficult and dangerous, and pit lighting is poor or absent. Most of the sheaves and their supports are in fair to good condition, but some bearings tend to overheat due to failures in the lubrication system.

1.5.4 Pulleys

Of the 635 carrying pulleys inspected, 120 were not rotating and had flat spots due to cable abrasion, were rotating intermittently and had flat spots, had poor bearings, or were out of their supports. At many designated stations the pulleys were missing. Maintenance records indicate that the following periods had elapsed since the malfunctioning pulleys were serviced by maintenance crews:

No.	Days
22	3-39
5	51-79
17	104-148
11	165-194
4	202-204
18	268-297
9	308-345
2	358-370
3	436-444
12	455-487
1	517

Sixteen locations had no servicing records. In addition, more than one tenth of the supports inspected had broken frames, or (in the case of wooden supports) were rotted, or were incorrectly placed in the channel. A major cause of pulley

malfunction is the obstruction of drainage and consequent accumulation of debris by pulleys fixed to supports resting on the channel bottom. Experimental aluminum pulleys with polyurethane lagging often arrive from the factory with aluminum shavings in the antifriction bearings, and the polyurethane is not bonded to the pulley.

1.5.5 Depression Beams

Stress analyses reveal that the Powell, Hyde, and experimental beams are all inadequately constructed to bear safely the impact of heavy traffic. The 5 in. diameter of the pulleys is too small to sustain for long periods the 600 rpm rotation caused by the rope. Broken or loose anchors can cause a dangerous malfunction. The design of the Powell beam is especially unsafe, because the arm tends to twist under loading due to the composite wood and steel construction and the bolts fastening the frame around the arm weaken the frame where it is rubbed by the passing grip; a jammed return mechanism or loose frame might catch the grip, bringing the car to a sudden halt. Of the 71 depression beams inspected, 34 had loose or distorted anchors and 9 showed considerable wear on the arms because of abrasion by the grip. Of the 142 pulleys, 37 were not rotating, were misaligned, or were not adequately supported by their bearings.

1.5.6 Rail

On 60 percent of the running rail the head is badly worn or chipped at the gauge line, providing inadequate support for the car wheels, which are prone to derailment because of their extremely short flange (11/32 in.). Gouged pavement along the running rail at many locations is evidence of numerous derailments. Many sections of running rail are loose because of loose bolts or corrosion of the yokes and fastenings. Gaps between sections and the joining of disparate types of rail have resulted in bowing when thermal expansion occurs. The arc weld method of repairing rail causes chipping.

About one third of the slot rail is seriously deteriorated or has been shaved to widen the slot where the rail has been bent by heavy traffic or construction. Unevenness of the slot width is common, and at several locations on the California line the rail has been deformed by the slot brake. Gaps between sections are hazardous because a loose end might catch the grip.

At turnouts, the head on 47 percent of the switch rails, 41 percent of the mate rails, and 47 percent of the frog rails is so badly worn that the wheel flange runs on the bottom of the flange groove. Of the 12 switch tongues, 7 were bent, showed considerable wear, or were poorly fitted

to the hole in the casting where the tongue is anchored, and 17 percent of the slot guides on switches and 18 percent of the slot points were also in poor condition.

1.5.7 Pavement

At 45 percent of 1695 inspection points, the pavement was gouged or had sunk along the rail or near hatches. Sinking in many instances is due to deterioration of the pavement plate.

1.5.8 Pull Curves

The car's difficulty in reducing speed at pull curves is hazardous, especially when rails are in poor condition, because of the car's outward thrust. Construction of the curves with sharply changing radii (compound curves) increases the danger. The short, 11/32 in. wheel flange, greatly increases the potential for derailment. Chafing bars wear the grip, and if loose might catch the grip, causing a severe accident. Heavy hatch covers that take two men to lift discourage maintenance. Conditions observed at various pull curves include badly worn running rail, rail guards, and slot rail; inadequate support of rail and other equipment by yokes; missing, worn, and malfunctioning pulleys (at Mason/Columbus for example, 44 were missing and 16 were stopped or malfunctioning out of 93 designated stations); worn and/or loose chafing bars; and gouged pavement, indicating derail-

ments. In one respect or another, poor conditions imperil the safe and efficient operation of the cars at every pull curve.

1.5.9 Bumper Bars

"Bumping" of the cable from the grip occurs about six times a year, often with serious damage to the cable; the cost of a new cable is about $30,000, not including installation or lost revenue. On three of the eleven bumper bars inspected the bell pulleys were not free to rotate, but otherwise all the bars were in good condition.

1.5.10 Safety Latches

Frames and springs of all six latches appeared to be in good condition and only one of the tongues showed significant wear.

1.5.11 Take-Rope Gypsies

Four of the five gypsies were in good condition, but on one the pulley was worn at the cable groove and the pulley bearing fit loosely around the shaft.

1.5.12 Turntables

Although all three turntables are operable, they have deteriorated. Some bearings on every table are sufficiently worn to warrant replacement. At the Powell-Market terminus, the top flange of the beams are extensively corroded, the circular rails are not level, the deck frame is warped, and large

sections of brick in the west and north walls are missing. The top flange of the beams of the Bay-Taylor turntable are also badly corroded, and there is considerable dry rot in the deck of the Hyde-Beach table.

1.5.13 Hatches

Nearly half the hatch covers inspected were worn thin by traffic, corroded, bent, or otherwise deteriorated. More than half the hatch frames were loose, had pieces broken off, or were so badly worn by traffic that the covers did not fit. The hatches are not designed for modern traffic loads.

1.5.14 Electrical Equipment

Traffic signal and crossbuck sensors are operating satisfactorily, but because of increased traffic more signals should be installed. Strand alarms are also operating properly, but more are needed.

1.5.15 Energy

The winding machinery imparts approximately 9,000 lbs of force to the cable, which is expended by driving itself, the cable cars, sheaves, and pulleys. Malfunctioning pulleys and other equipment increase greatly the force expended and therefore the amount of energy required to run the system.

1.5.16 Conclusions

The deterioration of the trackway has created a serious safety hazard. Sections of the conduit are collapsing.

Derailments due to the poor condition of the rail -- compounded by shallow wheel flanges -- are frequent and bound to increase as wear on the rail continues. Pull curves with worn rail, loose chafing bars, pulleys missing or not functioning, and worn switches invite a catastrophe. Depression beams are inherently unsafe because they cross the slot, but loose anchors, worn frames, and other such defects transform potential danger into peril. Pedestrians are in danger of injury from tripping in holes in the pavement at crosswalks.

Aside from questions of safety, the deterioration is rapidly swelling operating costs. Increasing track maintenance is required because of the corroded yokes and fittings. As the impaction of debris in the channel grows, even the hardiest struggle to maintain the pulleys is futile. Poor drainage in the sheave pits is damaging the equipment. Many sections of rail have little or no life left in them. Three major switches are barely functioning. Pavement plates are disintegrating. The turntables are corroded and worn. And many cable car employees have become so demoralized by the decay of the system that they are losing the pride and love that have kept the decrepit system alive. If the cable car system is to be preserved, the trackway must be rehabilitated.

Section 1.6

RECOMMENDATIONS

Repairs and other corrective maintenance are not sufficient to restore the trackway. Reconstruction or replacement and some redesign to take advantage of technological advances -- without changing the historic appearance of the system -- are necessary. Chin & Hensolt's recommendations include:

1.6.1 Cable

Study of the present cable and other cables to determine the proper specifications. Investigation of alternative cable materials, construction, and methods of lubrication, and an alternative material for the grip die to reduce wear on the cable and die and optimize the coefficient of friction.

1.6.2 Conduit

Replacement of the conduits, except for the infrequently used nonrevenue section on Hyde St between Washington and California sts, incorporating prefabricated concrete sections, with drains and equipment anchors. Development of suitable cleaning methods for removal of debris.

Replacement was found to be more economical and more practical from an engineering standpoint than partial reconstruction or replacement in kind.

1.6.3 Sheave and Turntable Pits

Reconstruction of the brick sheave pits located at California and Drumm, Powell and Market, Powell and Washington, and Bay and Taylor sts and turntable pits at Powell and Market and Bay and Taylor sts. Reconstruction of the roof and installation of sump pumps and improved drains in the other sheave pits. Relocation of Bay and Taylor sheave pit next to the turntable pit, placing them both farther south on Taylor St, and construction of a pedestrian mall between Bay and Francisco sts.

1.6.4 Pulleys

Establishment of uniform patterns for pulleys based on results of a testing and evaluation program for improvement of design and materials. Installation of pulley mounts above channel floor to eliminate drainage obstruction and facilitate cleaning of channel.

1.6.5 Depression Beams

Investigation of a means of eliminating depression beams; or redesign of the Hyde type beam to preclude jamming, enable it to better sustain heavy traffic loading, and reduce the maintenance required as a result of its dirty environment.

1.6.6 Rail

Use of girder rail throughout the system because of its flange channel, or, if girder not available, 60 lb Tee rail,

except 100 lb Tee rail on outside of pull curves, and Thermit welding of sections. Replacement of wheels with ones having flanges at least 5/8 in. in depth. Use of uniform slot rail, with beveled ends to prevent dislocation that might catch grip. Design of uniform, replaceable sections for turnouts.

1.6.7 Pavement

Repavement with asphalt near rails, except for brick at Powell St mall and Market-Drumm terminus, to facilitate track repairs.

1.6.8 Pull Curves

Establishment of minimum 50 ft radius for all pull curves where possible, and replacement of combination curves (segmented decrease of radius after beginning of turn) with spiral curves (continuous decrease). Investigation of reduction in cable car speeds. Replacement of present chafing bar with Tee rail, and installation of an automatic lubrication system for bars.

1.6.9 Bumper Bars

Installation of limit switches to shut down winding machinery automatically if gripman passes let-go warning point without dropping cable.

1.6.10 Take-Rope Gypsies

Construction of dips in track to replace gypsies, otherwise retention of present gypsies.

1.6.11 Safety Latches

Retention of present type of safety latch.

1.6.12 Turntables

Replacement of present turntables with electrically operated ones, the design to include placing support rails close to rim to provide better resistance to impact of car when entering turntable. Enlargement of pits and installation of entrances at side of pits to permit inspection of table while in use.

1.6.13 Hatches

Redesign of hatch frames and covers, with a view to restricting the weight to be lifted by one man to 50 lb, preventing dislodgement by heavy traffic, facilitating inspection of subsurface equipment by use of grating, and securing covers in an open position while maintenance work is being done on equipment.

1.6.14 Electrical Equipment

Installation of railroad-type flashing red lights at various pull curves and intersections to warn motorists that cable cars are about to cross their path; more strand alarms, to provide one every 2000 ft; an automatic lubrication system

for sheaves and other equipment; an automatic temperature monitoring system for bearings; and a communication system between cable car and barn and between sheave pits and the barn -- via central control. Installation of electrical raceway in new conduit to provide lines for trackway electrical equipment.

1.6.15 Energy

Replacement of Hyde St nonrevenue track with 3000 ft independent loop driven by a satellite power unit, in order to eliminate the equivalent of four 90° bends. Rereeving Powell-Mason line cable to reduce distance between center of load and winding machinery -- or study of feasibility of separating Powell and Mason cables. Study of feasibility of rerouting to eliminate pull curves and substituting drift curves for some pull curves. All these measures would conserve energy and increase cable life. (See Figure 1.6.a.)

Section 1.7

TESTING AND EVALUATION

To provide the most efficient and economical components for the rehabilitated trackway, Chin & Hensolt recommends establishment of a testing and evaluation program of new materials. Investigation would be made of:

- o Alternative lubricants to replace the present pine tar, with its inherent problems;
- o High molecular weight polymer for pulley facings, self-lubricating pulley bearings, self-lubricating facing of chafing bars, and self-lubricating cable guides;
- o Alloys for grip dies and cable car wheel runs.

Section 1.8
MAINTENANCE

Operating 20 hrs a day, seven days a week, the cable car equipment is used 7300 hrs a year -- four times as much as the equipment in a single-shift industrial facility -- and consequently needs that much more maintenance. But proper maintenance is hindered by the difficulty and, in some instances, hazards involved in reaching subsurface equipment. Maintenance is further discouraged by encumbering paper work, which requires clerical skills of workmen and inspectors. Replacement parts often are not available commercially and must be manufactured by cable car personnel. And responsibility for maintenance is divided among various city departments: the cable car division handles cable machinery, the Ways and Structures Department is in charge of rail, hatches, and procurement, the Department of Electricity has jurisdiction over traffic signals, and

Hetch Hetchy Water and Power takes care of electrical equipment.

But in addition to these physical and organizational problems, there is a lack of and disregard for maintenance in some areas. The fact is that in the Columbus to Mason and Mason to Columbus pull curves 60 of the 93 designated pulleys were malfunctioning or missing; at least 18 of 120 malfunctioning carrying pulleys had not been serviced for a year or more; the winding machinery was operating for about a year with loose gib keys and loose and broken bolts; and depression beams that are twisted and have bolt heads projecting beyond the cam surfaces have been installed in the street.

Chin & Hensolt therefore recommends that inspection not be performed by persons responsible for doing repair work. When conditions are uncovered that create a hazard to personnel or equipment while the system is in operation, the system should be shut down until repairs are made. Safety and preservation of the equipment must never be compromised.

Section 1.9

ROUTE MODIFICATIONS

With a view to increasing the operational efficiency of the cable car system and providing better service, certain suggestions have been made for modification of the present cable car routes.

1.9.1 Powell-Mason Line Reroute

Since pull curves increase the cable load by an estimated seven percent each and present some of the most critical safety and maintenance problems, consideration should be given to eliminating the seven pull curves on the Mason-Powell line by rerouting part of the line. Powell-Mason cars would proceed one way on Powell to Jefferson, turn west on Jefferson, and return on Mason, rejoining the present route on Columbus Av. An additional advantage would be elimination of the turntable at Bay and Taylor sts. (See Figure 1.9.a.)

1.9.2 Powell-Mason Line Extensions

If the rerouting of the Powell-Mason line is not adopted, better service to Fisherman's Wharf might be provided by

- Extending the line along Taylor St to Jefferson St (see Figure 1.9.b); or

- Continuing the line north of Columbus Av on Mason St to Jefferson, eliminating the pull curves at Columbus Av and Taylor St, with a consequent substantial reduction in the energy load on the system (see Figure 1.9.b).

1.9.3 California and Hyde Lines

To allot more cars to the busy Hyde line and make better use of the lightly travelled section of the California line west of Hyde St, the California and Hyde lines might be combined -- for which, of course, there is a historical precedent. Cars travelling west on California would turn onto Hyde, proceed to the Victorian Park terminus, and then return to California, where they would turn west and follow the California route. Direct service would thus be provided from downtown California St to Nob Hill, Telegraph Hill, Ghirardelli Square, the Cannery, and nearby Fisherman's Wharf.

Extension of the California line east to the Embarcadero and west to Japan Center by way of Pacific Heights is feasible. (See Figure 1.9.c.)

Section 1.10

CONSTRUCTION SCHEDULE

For the sake of economy, Chin & Hensolt recommends that reconstruction of the trackway be concurrent with

rehabilitation of the car barn and that the work be scheduled over a 20-month period, during which the system would be shut down.

The system would be divided into five segments:

(1) Washington, Jackson, Powell, and Hyde sts near the barn -- the "loop" common to all four lines;

(2) The California line;

(3) The Powell line;

(4) The Mason line; and

(5) The Hyde line

All segments would be reconstructed at the same time. Immediate installation of the proposed precast concrete conduit following excavation would minimize the interference with traffic.

Since ordering, shop drawing, approval, fabrication, and delivery of new winding machinery will require 18 months and four months must be allowed for setting up the machinery, connecting utilities, and startup testing, the winding machinery should be ordered six months before award of the barn and trackway reconstruction contracts.

Allowing for a 22-month design period (seven for preliminary drawings and 15 for final design), four months for review (two preliminary review and two final review), and three months for bid and award, construction could begin

in November 1981. Cable car service would be resumed in July 1983. (See Figure 1.10.a.)

Section 1.11

INTERIM REHABILITATION

The deterioration of the trackway is accelerating at such an alarming rate that unless effective measures are taken immediately the cost of maintenance will soon become prohibitive. Until the rehabilitation program recommended by Chin & Hensolt is instituted, the following measures should be immediately adopted to restrain further deterioration, with its attendant safety hazards.

(1) Slow cable speed substantially to reduce wear and the potential for accidents.

(2) Intensify corrective and preventive maintenance, assigning administrative responsibility to an independent authority. Corrective maintenance should include:

- o Cleaning of the channel.
- o Installation of pulleys in all stations where pulleys are missing,and replacement or repair of all malfunctioning pulleys.
- o Repair of any substandard part of a depression beam.

- Replacement of defective pull curve chafing bars, pulley supports, inside rails, and guards.
- Modification of slot rail butts, welding them together or beveling them in the direction of traffic.
- Repair of turnout switches and other components.

Preventive maintenance should include diligent inspection of all components to detect new signs of deterioration (and order immediate repairs) and ensure that deterioration has not recommenced on parts that have been repaired.

In the event that the recommended rehabilitation program is not undertaken within a reasonable period, we urge immediate adoption of the following measures:

(1) Replacement of the present cable with cable conforming more closely to cable supplied under a previous (Edwards) contract.

(2) Programed replacement of improved depression beams (see Section 3.5).

(3) Programed rehabilitation of pull curves, including new pulley frames and mounting supports (see Section 3.4), new hatch covers with grating (see Section 3.13), and new Tee-rail chafing bars (see Section 3.8).

(4) Replacement or (where possible) repair of badly deteriorated turnouts (see Section 2.6).

(5) Replacement of defective running rail and rail guards (see Section 2.6).

(6) Replacement of all carrying pulleys with cast-steel 9-1/2 in. wide-faced pulleys, with antifriction bearings.

(7) Installation of temperature monitoring on all major sheaves.

(8) Establishment of an intensified channel-cleaning program.

(9) Installation of larger drains in the sheave pits.

(10) Establishment of a testing and evaluation program to provide a basis for the rehabilitation program.

Chin & Hensolt recommends that planned extensions of the system be postponed until new design concepts for the trackway are completed.

Section 1.12

COST ESTIMATES

COST ESTIMATE OF TOTAL RECONSTRUCTION OF THE SAN FRANCISCO CABLE CAR TRACKWAY

SUMMARY	COST: JUNE 1979	COST: SEPT. 1982*
Traffic control	$ 160,000	$ 236,000
Demolition and removal of existing conduit	$ 2,000,000	$ 2,948,000
Installed precast concrete conduit	$ 8,110,000	$11,955,000
Installed 60-lb Tee rail and accessories (990 tons)	$ 1,870,000	$ 2,757,000
Installed slot rails	$ 970,000	$ 1,430,000
Switches (15)	$ 370,000	$ 545,000
Pits, pulleys, take-outs, gypsies, bumper bars, latches, depression beams, drains, manholes, and accessories	$ 642,000	$ 946,000
Sheave Rooms		
1. Replacement of roof structures, openings, and hatches (6 locations)	$ 122,000	$ 180,000
2. Total replacement (4 locations)	$ 438,000	$ 646,000
Turntables (3)	$ 600,000	$ 884,000
Rehabilitation of tail sheaves, bend sheaves, and double sheaves	$ 50,000	$ 74,000
Electrical and monitoring systems	$ 650,000	$ 958,000
Subtotal	$15,982,000	$23,559,000
15% contingency	$ 2,397,000	$ 3,534,000
	$18,379,000	$27,093,000
Gen. contractor's site establishment, equipment, supervision, job expense, overhead, profit, and bonds: 18%	$ 3,308,000	$ 4,877,000
TOTAL	$21,687,000	$31,970,000

* Escalated through 39 months at a rate of 1% per month, compounded.

COST ESTIMATE OF THE PARTIAL REPLACEMENT-IN-KIND
OF THE SAN FRANCISCO CABLE CAR TRACKWAY

SUMMARY

Removal of existing rails, equipment, and road surface	$ 900,000
Installation of new rails, pits, and paving	$ 6,750,000
Replacement of hatch covers and equipment	$ 1,700,000
Miscellaneous work	$ 150,000
Traffic control	$ 150,000
Subtotal	$ 9,650,000
*20% contingency	$ 1,930,000
	$11,580,000
General contractor's site establishment, equipment, supervision, job expense, overhead, profit, and bonds: 18%	$ 2,084,400
Total	$13,664,400

*Due to hidden conditions and inherent high risks to contractor, resultant high bids must be expected.

Section 1.13

CONCLUSION

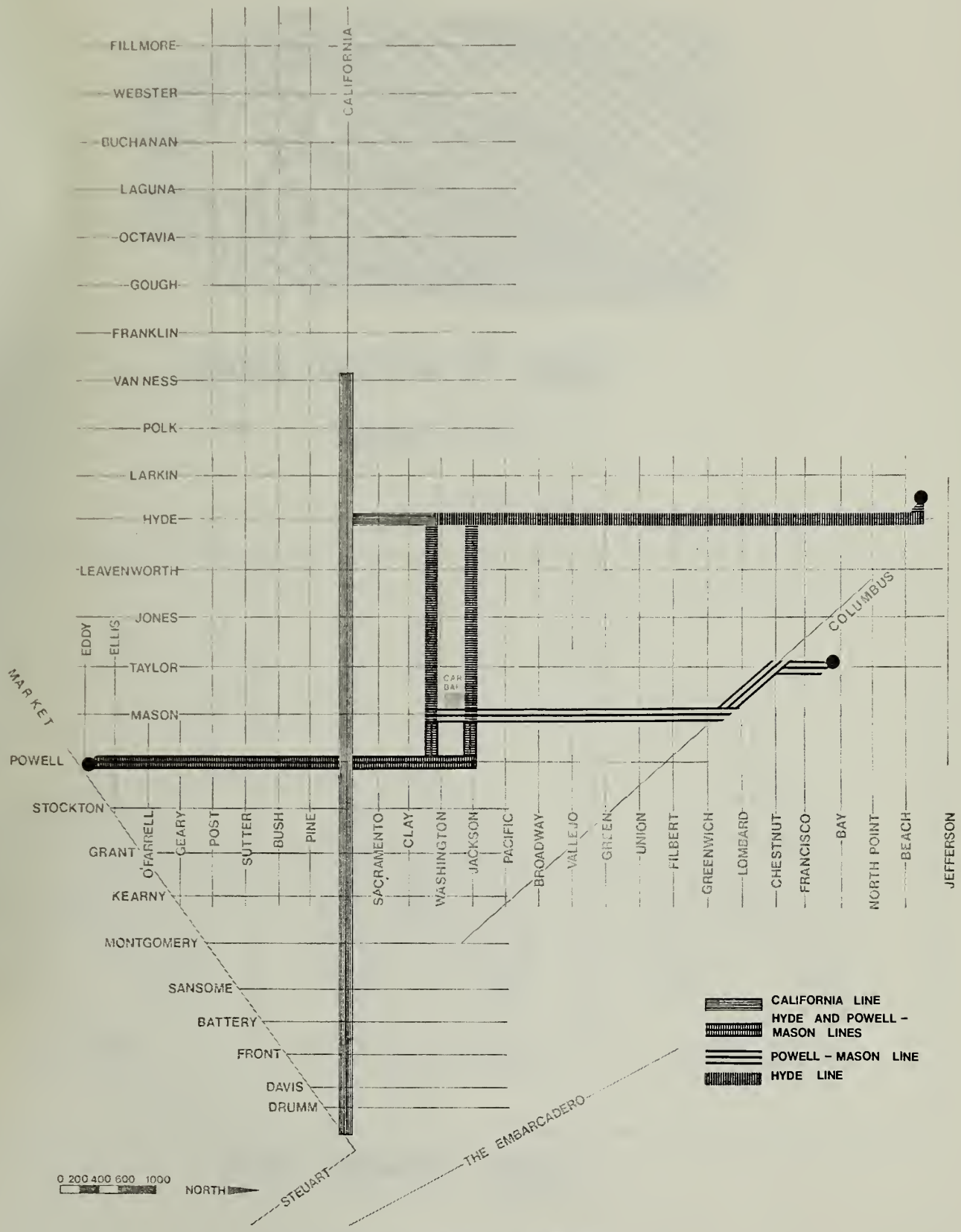
As a result of our thorough inspection and evaluation of the trackway, we have concluded that an extensive rehabilitation is necessary if safety and economy are to be restored to the cable car system. The conduit has deteriorated to the point that it is no longer able to provide secure support for the rail and other equipment. The rail is so worn that derailments are an almost daily occurrence. Malfunctioning pulleys draw excessive energy and greatly increase wear of the cable. Depression beams are not designed for modern day traffic loads and consequent malfunctions have caused serious accidents. Soon the increasing cost of maintenance will render the system inoperable.

Chin & Hensolt urgently recommends that a program of thorough reconstruction and replacement begin as soon as possible. The program would include complete reconstruction of the conduit, using precast concrete, which is both durable and economical. The tracks must be rerailed. Modern pulleys must be installed. The depression beam must be redesigned to enable it to bear the stress created by vehicular traffic. And most of the other components similarly require modification or replacement to meet acceptable standards of safety and economy.

Since reconstruction of the conduit is by far the largest cost item, a careful study was made of alternatives to replacement, and it was found that repair or partial reconstruction are unfeasible from both an engineering and economic standpoint. The use of precast concrete, specially designed to include rail and equipment placements, was found to be far less expensive and much more efficient than replacement in kind. The conduit would be constructed in sections, which could be installed at the rate of 150 to 200 ft a day, minimizing interference with traffic. Since the top flange of the conduit would be designed to support traffic, automobiles and trucks would be able to cross it almost immediately after installation.

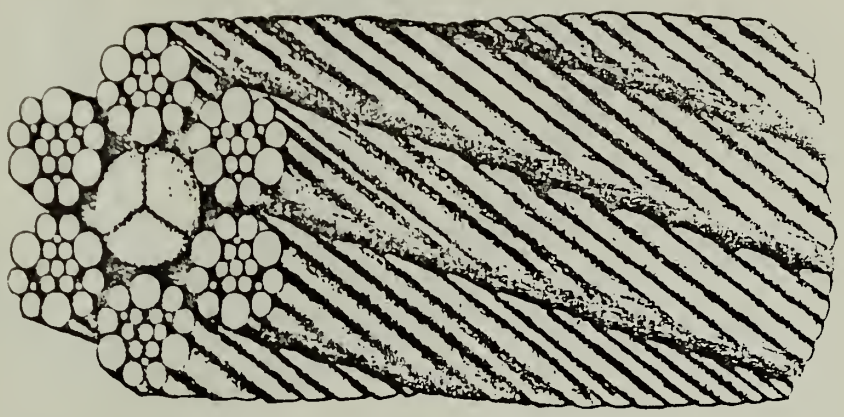
The cost of the rehabilitation is estimated at $21,687,000 in June 1979 prices and $31,970,000 in September 1982 prices. This capital outlay must be measured against the rapidly increasing cost of maintaining the antiquated system, and the cost in personal injury that is bound to increase if rehabilitation is not undertaken. For those of us who love the cable car system -- not only us San Franciscans, but people all over the world -- the benefits to be derived are incalculable.

Figures



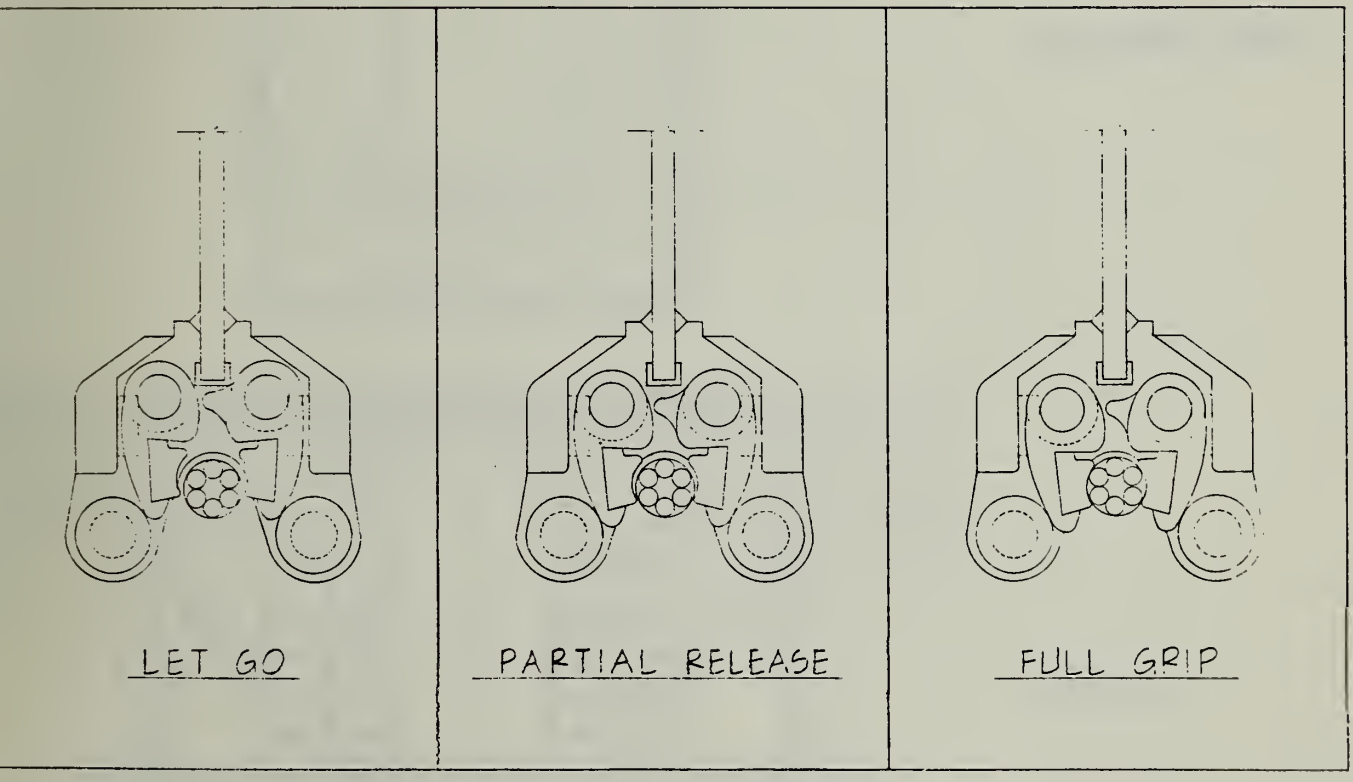
CABLE CAR LINES

FIGURE 1.2.a



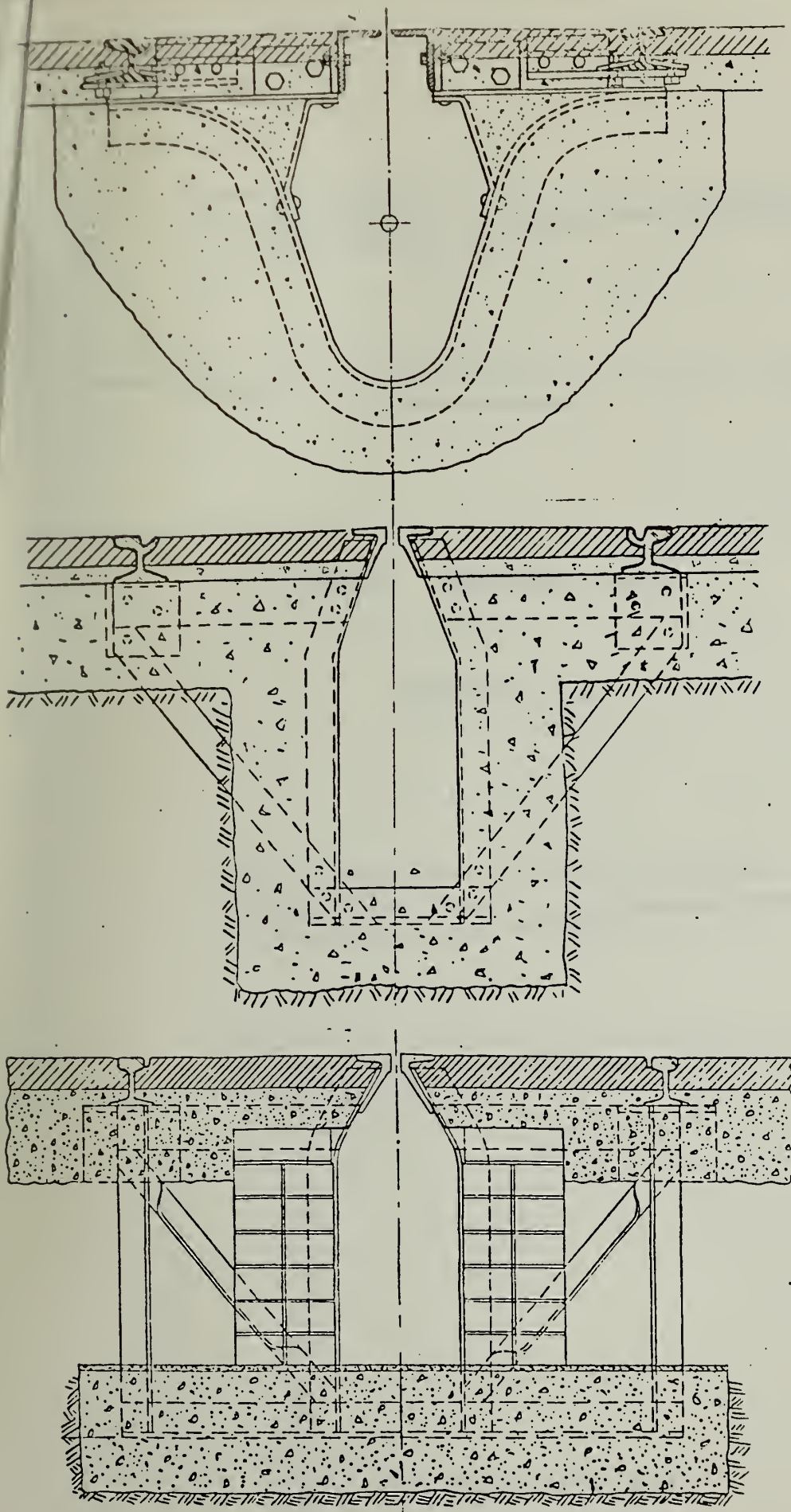
CROSS SECTION OF CABLE

FIGURE 1.2.b



GRIP ENGAGING CABLE

FIGURE 1.2.c



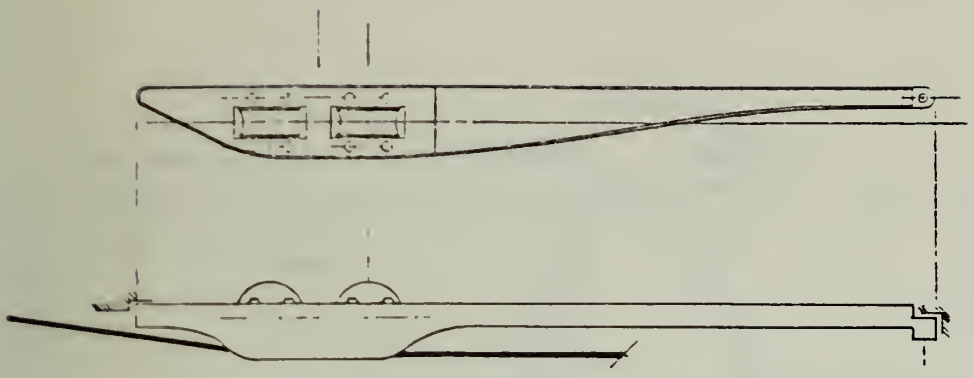
CALIFORNIA 1877

CALIFORNIA 1890

POWELL

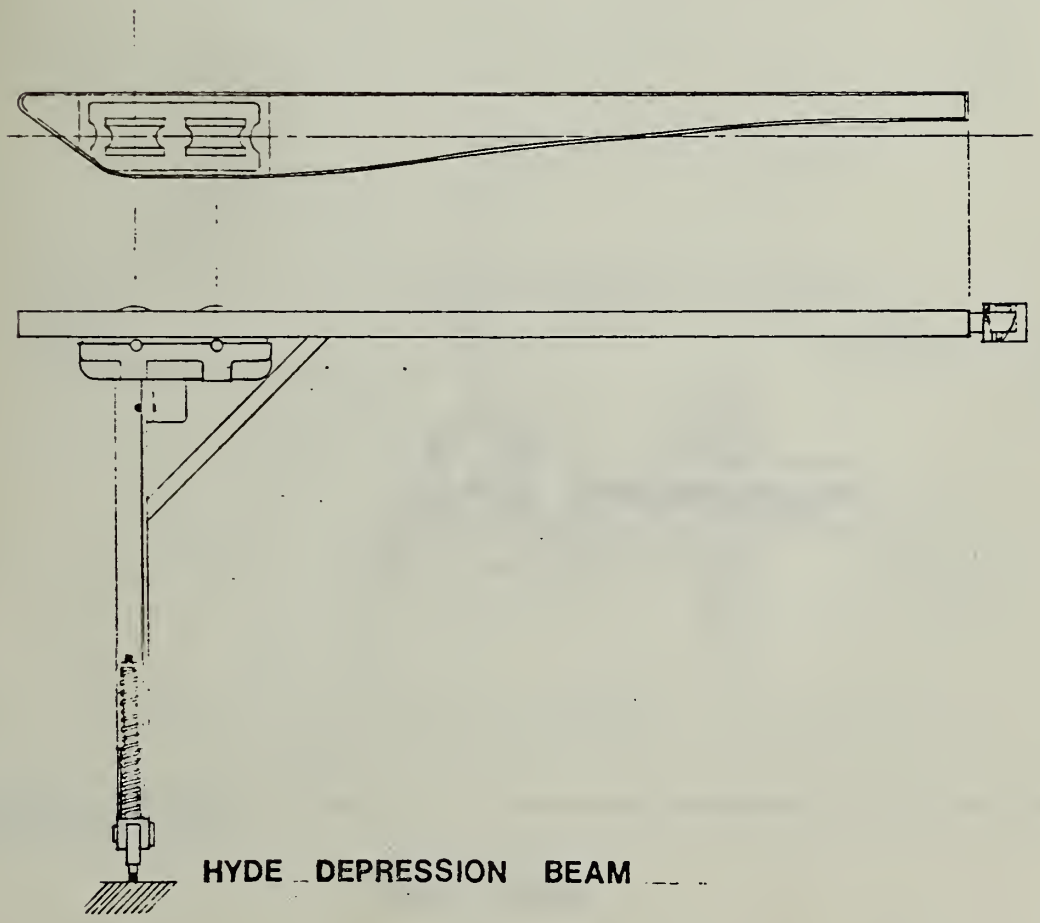
TYPES OF CONDUIT

FIGURE 1.2.d



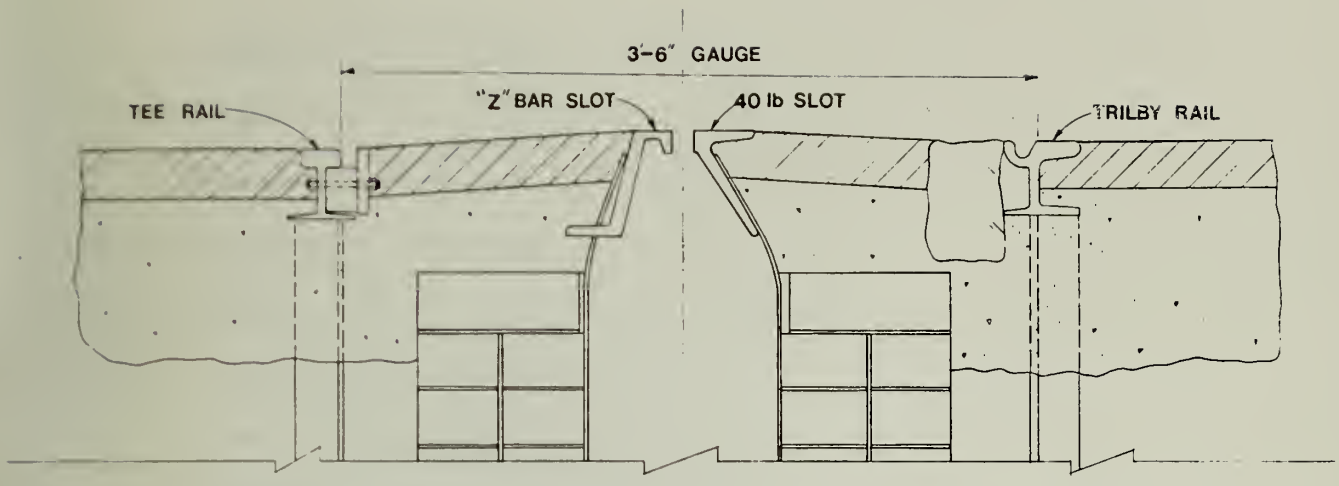
POWELL DEPRESSION BEAM

FIGURE 1.2.e



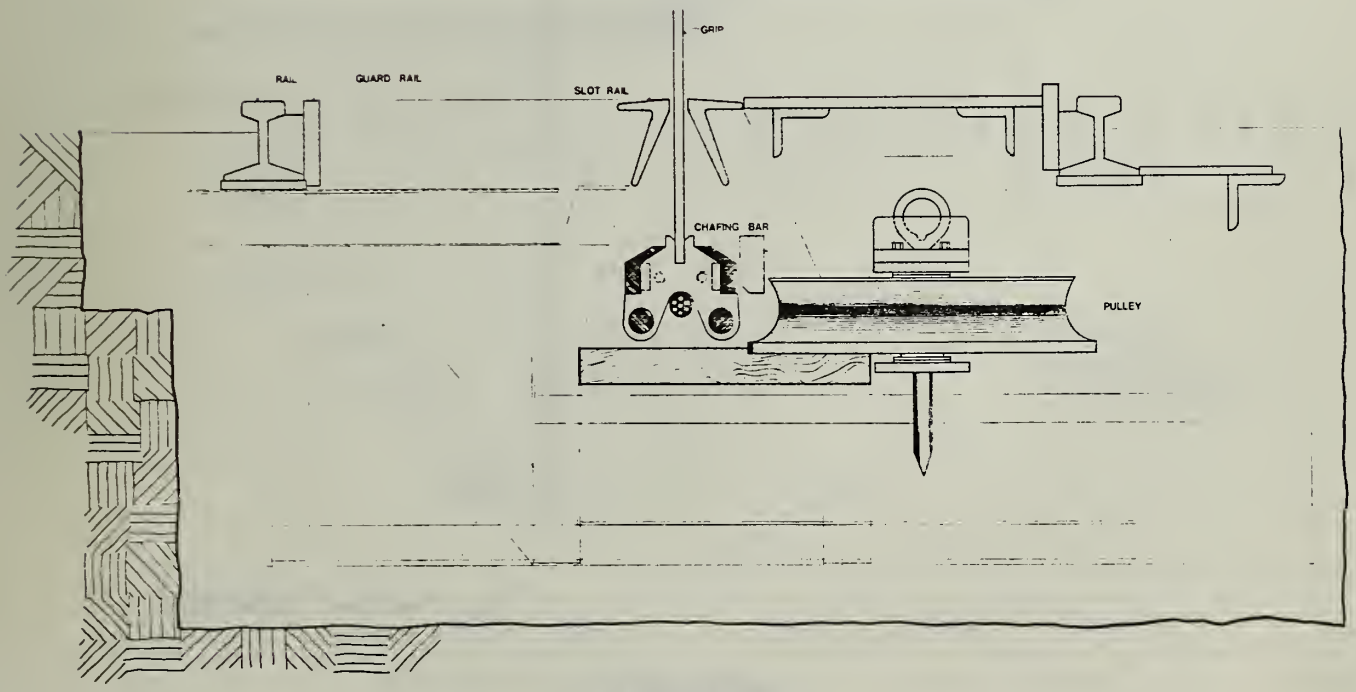
HYDE DEPRESSION BEAM

FIGURE 1.2.f



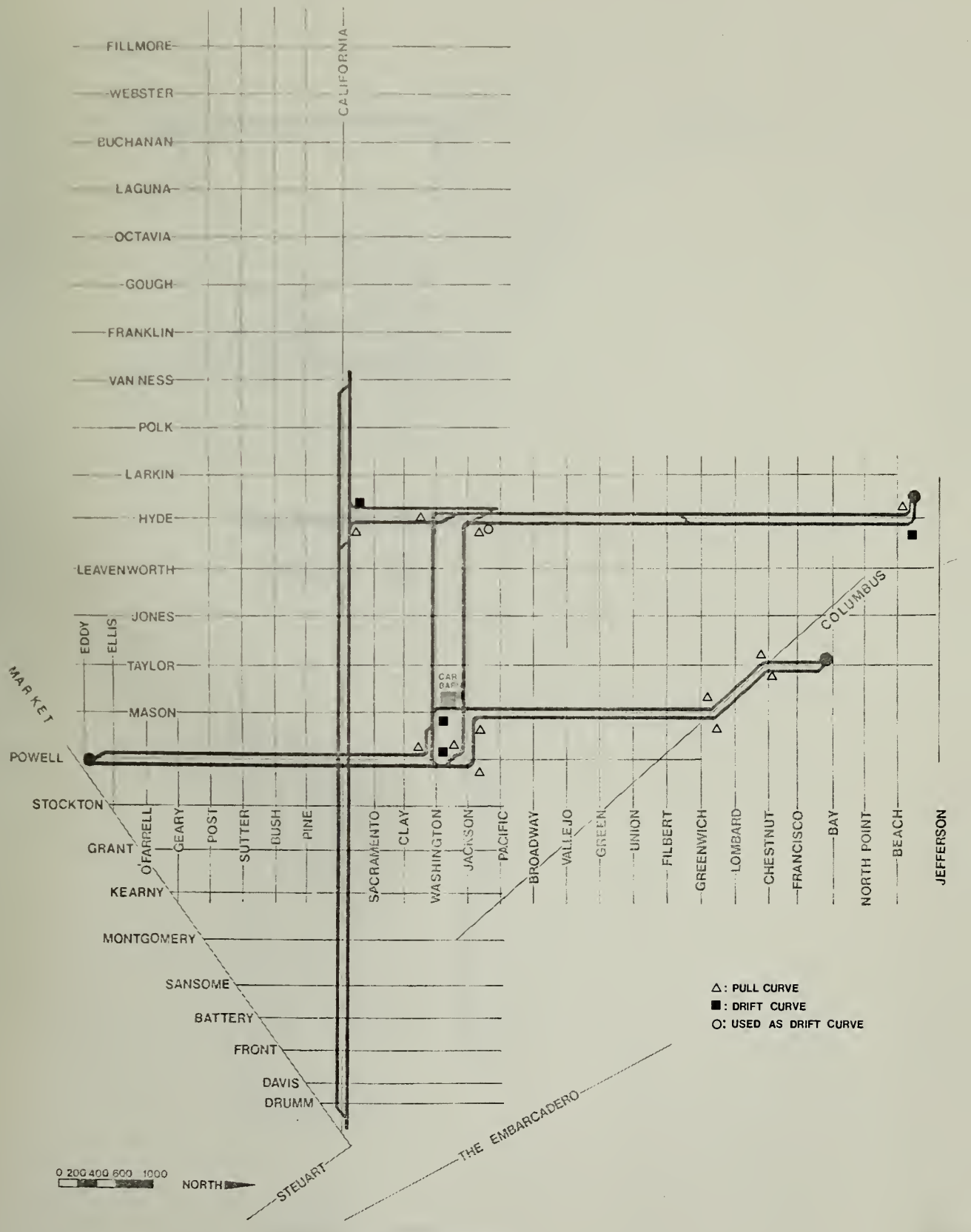
CONDUIT SECTION SHOWING TYPES OF RAIL

FIGURE 1.2.g



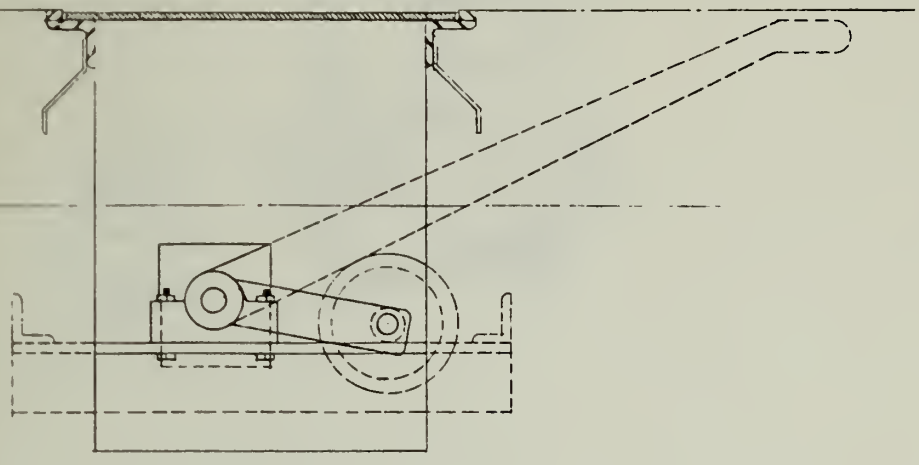
PULL CURVE

FIGURE 1.2.h



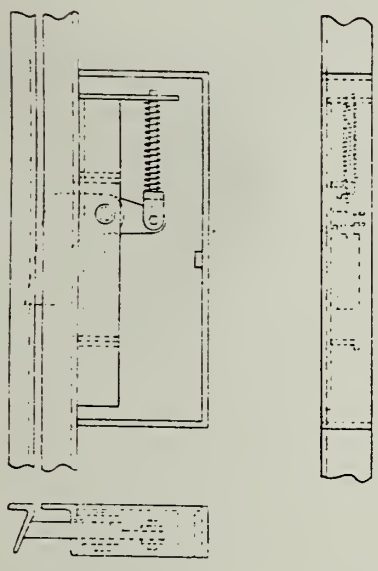
CURVES

FIGURE 1.2.i



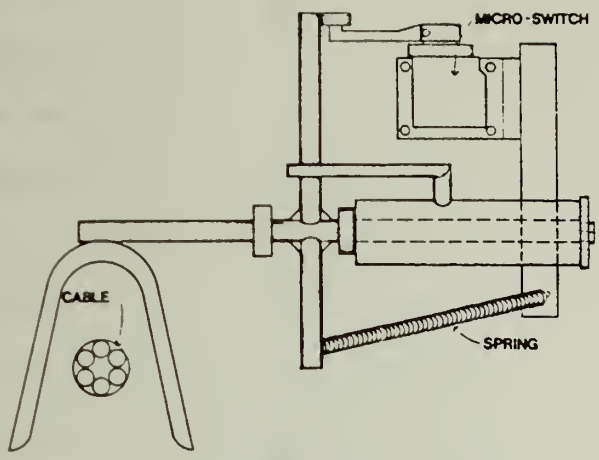
TAKE-ROPE GYPSY

FIGURE 1.2 j



SAFETY LATCH

FIGURE 1.2:k



STRAND ALARM

FIGURE 1.2.1

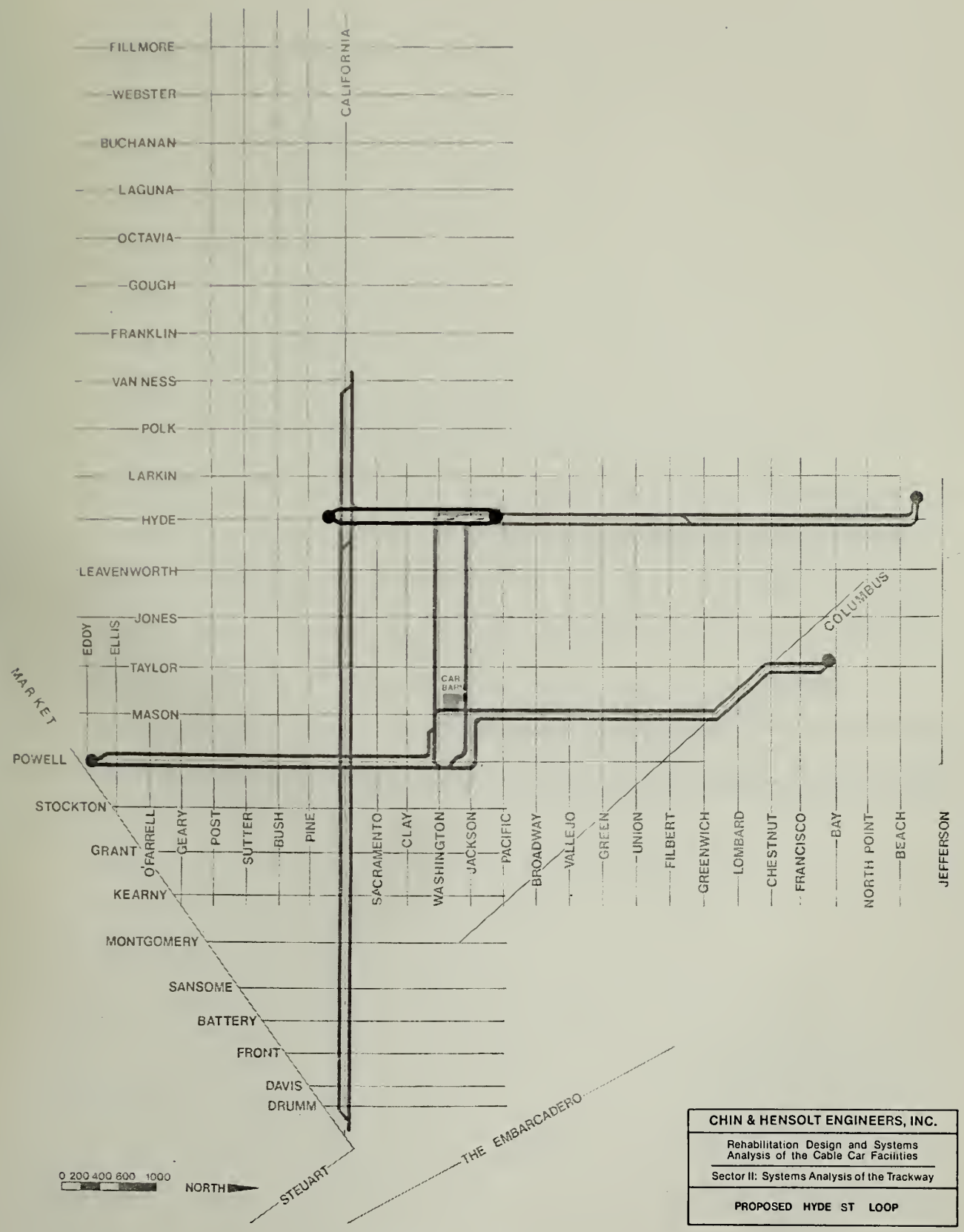
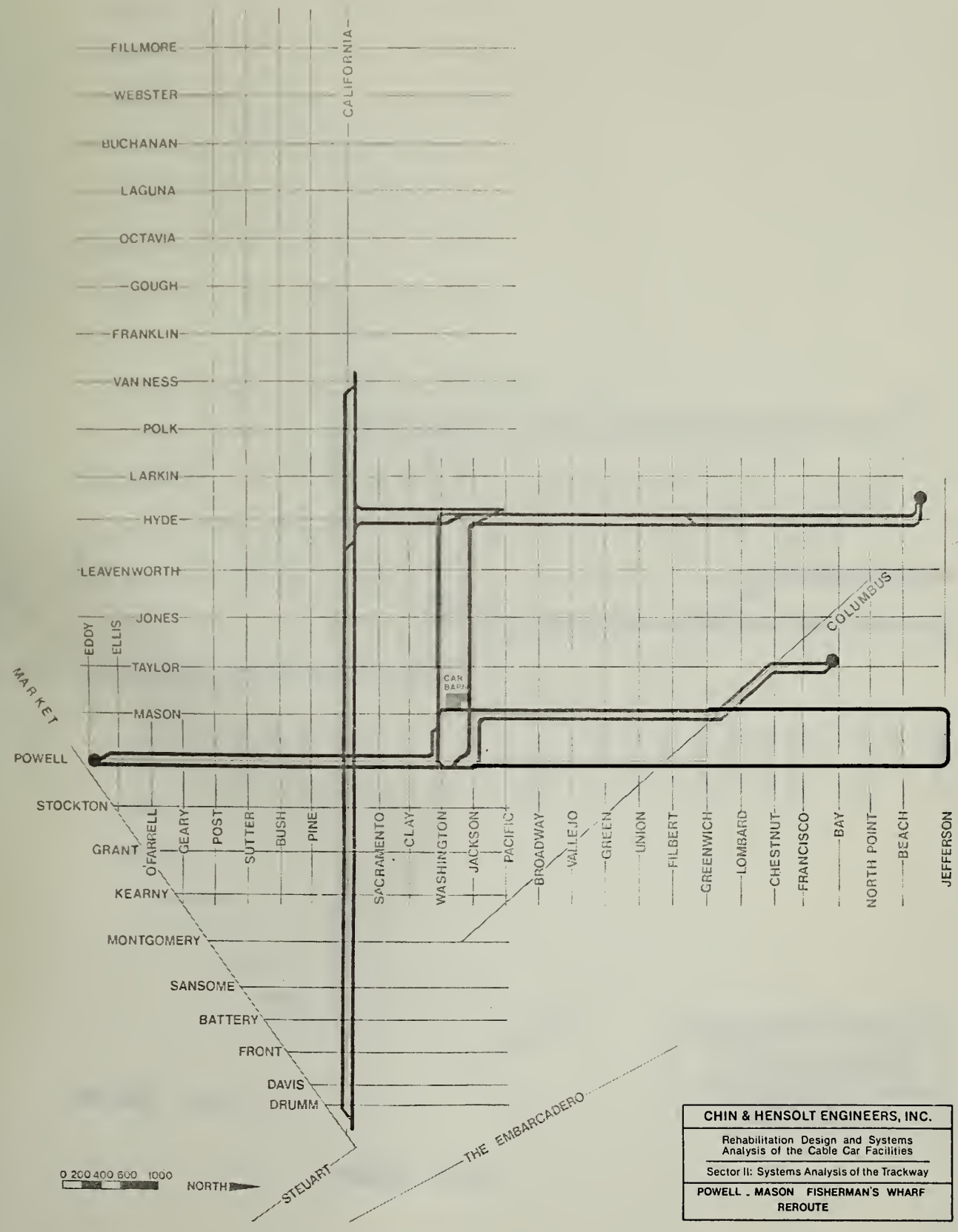
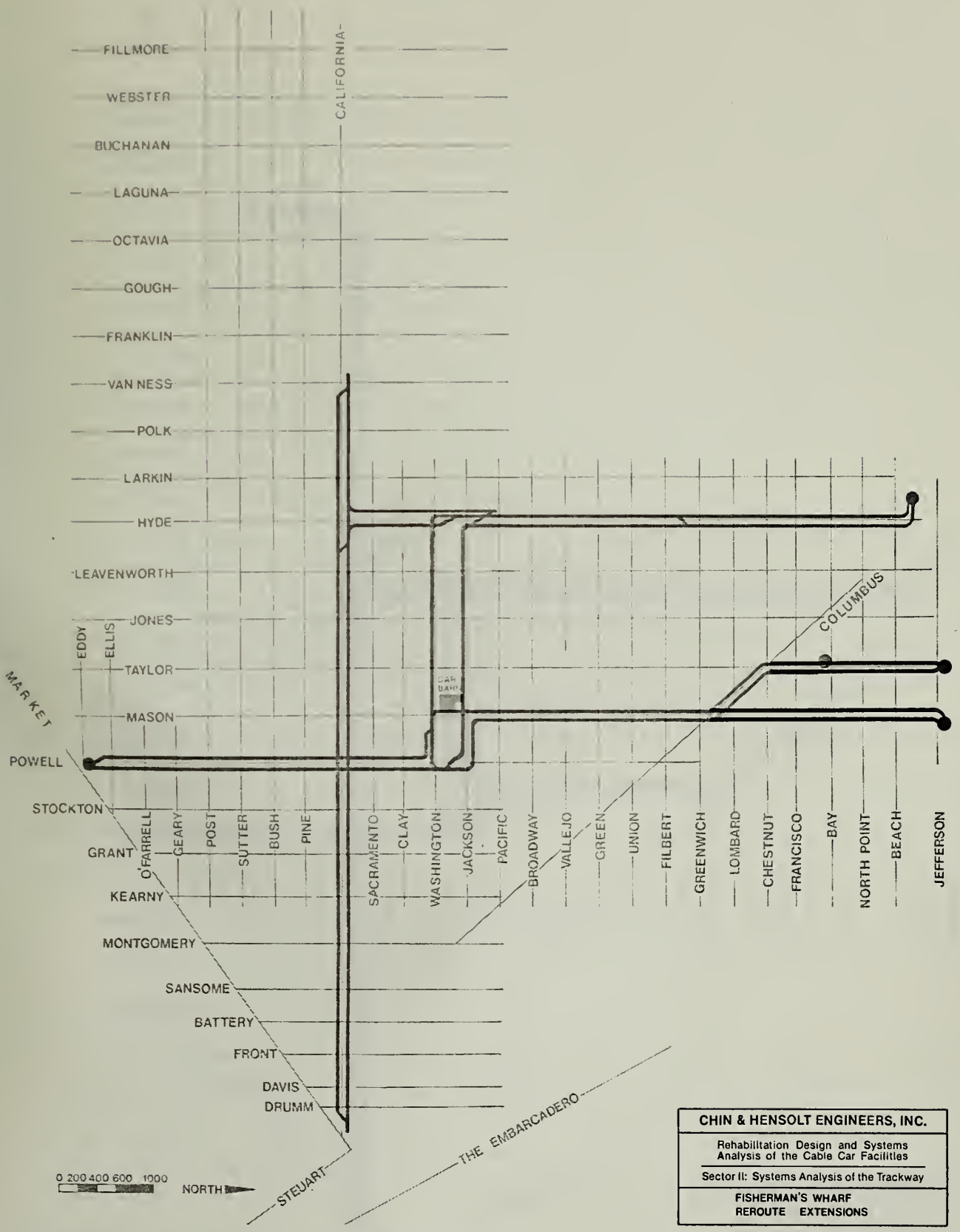

FILLMORE
WEBSTER
BUCHANAN
LAGUNA
OCTAVIA
GOUGH
FRANKLIN
VAN NESS
POLK
LARKIN
HYDE
LEAVENWORTH
JONES
TAYLOR
MASON
POWELL
STOCKTON
GRANT
KEARNY
MONTGOMERY
SANSOME
BATTERY
FRONT
DAVIS
DRUMM
CALIFORNIA
EDDY
ELLIS
MARKET
O'FARRELL
GEARY
POST
SUTTER
BUSH
PINE
SACRAMENTO
CLAY
WASHINGTON
JACKSON
PACIFIC
BROADWAY
VALLEJO
GREEN
UNION
FILBERT
GREENWICH
LOMBARD
CHESTNUT
FRANCISCO
BAY
NORTH POINT
BEACH
JEFFERSON
COLUMBUS
CAR BARN
THE EMBARCADERO
STEUART
0 200 400 600 1000
NORTH
CHIN & HENSOLT ENGINEERS, INC.
Rehabilitation Design and Systems Analysis of the Cable Car Facilities
Sector II: Systems Analysis of the Trackway
PROPOSED HYDE ST LOOP

FIGURE 1.6.a



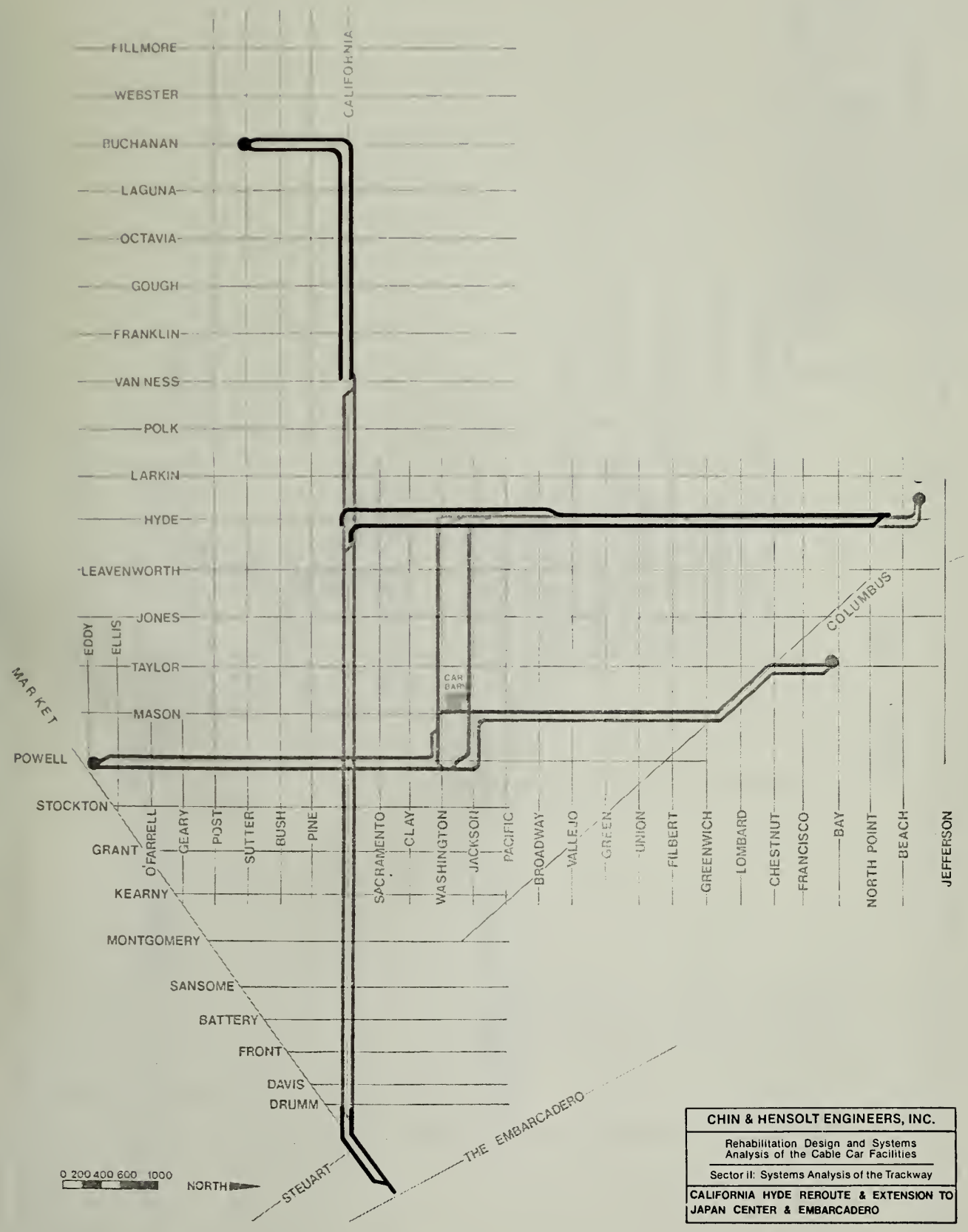
CHIN & HENSOLT ENGINEERS, INC.
Rehabilitation Design and Systems Analysis of the Cable Car Facilities
Sector II: Systems Analysis of the Trackway
POWELL - MASON FISHERMAN'S WHARF REROUTE

FIGURE 1.9.a



CHIN & HENSOLT ENGINEERS, INC.
Rehabilitation Design and Systems Analysis of the Cable Car Facilities
Sector II: Systems Analysis of the Trackway
FISHERMAN'S WHARF REROUTE EXTENSIONS

FIGURE 1.9.b



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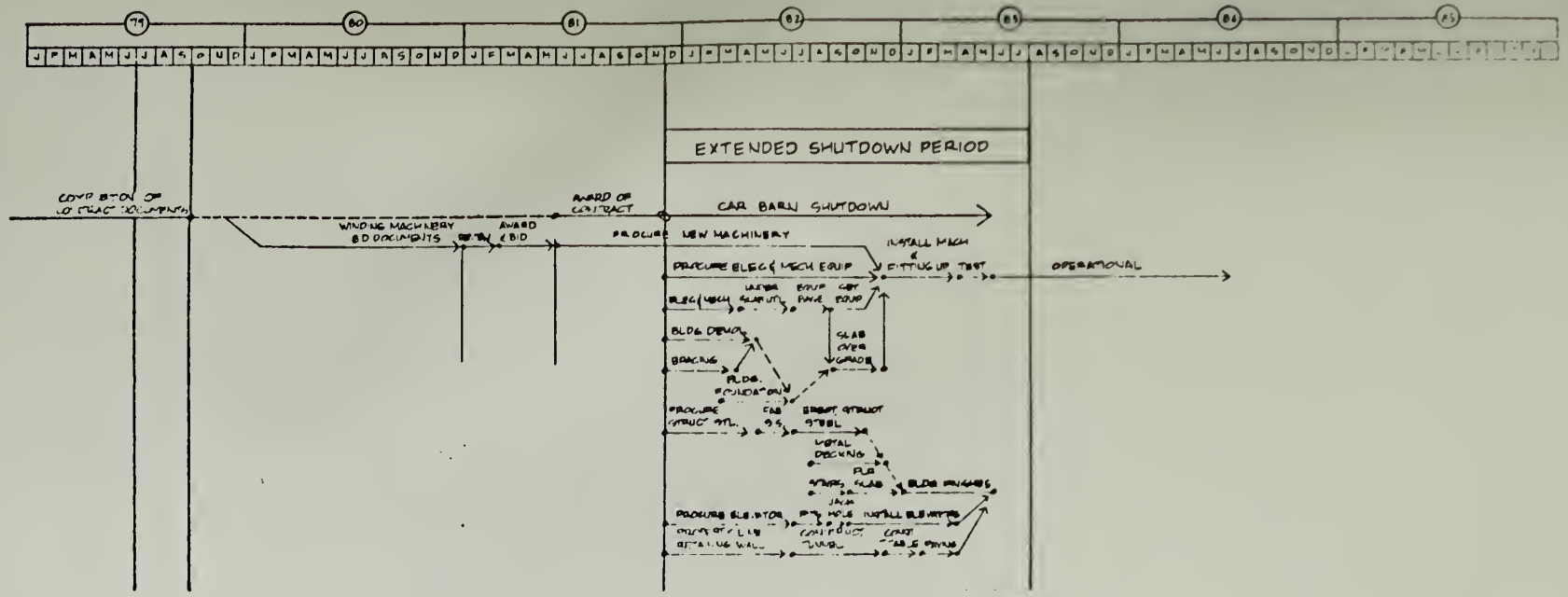
CALIFORNIA HYDE REROUTE & EXTENSION TO JAPAN CENTER & EMBARCADERO

FIGURE 1.9.c

CAR BARN



TRACKWAY

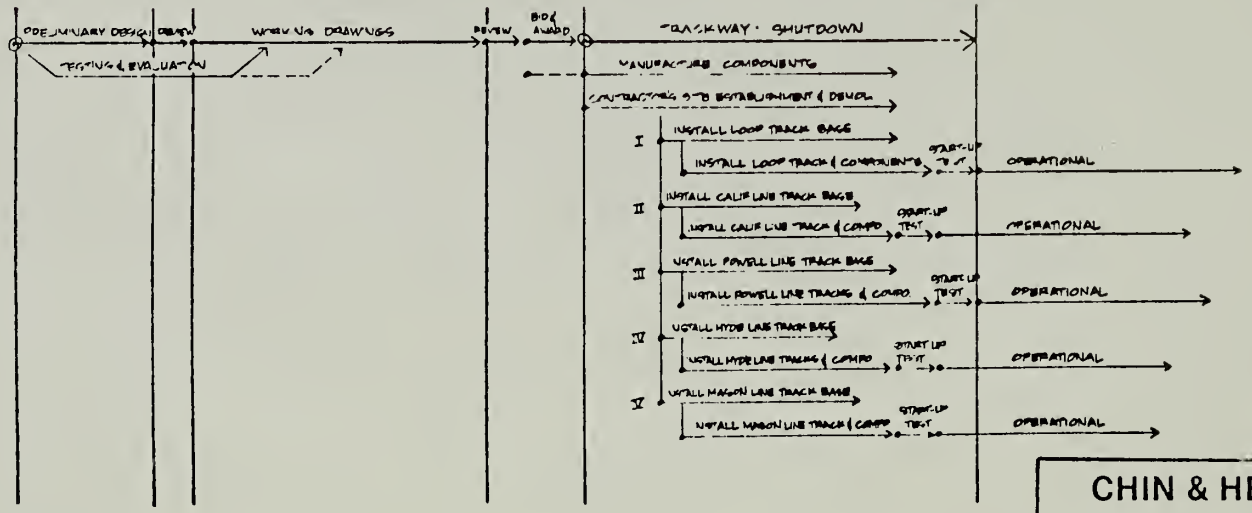


FIGURE 1.10.a

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PROPOSED DESIGN AND CONSTRUCTION SCHEDULE OF BARN AND TRACKWAY